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SUBJECT: Orbital Lifetime Capabilities of Digital Programs RMDAP and Monster

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1.0 SUMMARY

A cursory study was made of the orbital lifetime study capabilities of the Reference Mission Design and Analysis Program (RMDAP) and the Apollo Mission Planning and Real-Time Rendezvous Support Program (ARRS or Monster). Output and program versatility, that is, the methods with which each program permits user definition of the major factors affecting orbital lifetimes, are discussed. In addition, orbit maintenance is examined and sample runs are compared. Since each program has special capabilities in different areas, it is left to the investigator's discretion as to the preferable program to employ for his lifetime study purposes.

2.0 DISCUSSION

The compilation of the orbital lifetime study capabilities of RMDAP and Monster is based upon available sources, namely, user manuals (References 1 and 2), program runs, and RMDAP listings. In electing to perform orbital lifetime studies with either RMDAP or Monster, the corresponding features of each were investigated: output,

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atmosphere models, drag coefficient, vehicle mass, effective drag area, state vector initialization, orbit keeping, trajectory prediction models, and event termination.

2.1 Output

The general output structure of RMDAP consists of information blocks. The user may select for printout as many such blocks as desired. The data within each block are categorized, such as, geographic output; geocentric osculating elements; perturbative accelerations. Output is controlled by print control flags. The user may specify the output of several print blocks to be controlled by the value of a user selected argument (or arguments). For example, in order to observe the decay of the apogee and perigee of a vehicle's orbit, the user may elect to have the geographic and geocentric osculating elements print blocks printed every time a change of 180 degrees occurs in true anomaly. In addition to the print blocks desired, a title, vector time data, and orbit counts are printed at each print point.

A special Report Generator is provided for RMDAP users who prefer custom formatted tables consisting only of pertinent data in an easy-to-read form. For this study, an attempt was made to ascertain how simple and practical it was to use the Report Generator. Several attempts were made to feed the generator a test run. Each resulted in a failure and it was concluded by this writer that

either the Report Generator or its interface with RMDAP is not working properly, or that it is not documented well enough to aid the unfamiliar user in debugging his input. A special version of RMDAP is available which only prints a tabular ephemeris without employing the Report Generator. The data produced may also be stored on a tape for future processing.

Some of Monster's output is in the form of displays containing maneuver solutions and execution and planning table information, similar to the displays in the Real-Time Computer Complex program. Many processors are provided to produce specialized output, most of which are in tabular form. Some of the output available are groundtrack data, state vectors in different systems, orbit digitals, ground elapsed time (g.e.t.) of apogee and perigee, g.e.t. of the ascending node, and g.e.t of the start of each revolution. Ephemerides can be produced with either of two processors, but not in a simple table format as with the special version of RMDAP.

2.2 Atmosphere Models

Both RMDAP and Monster incorporate the 1962 U.S. Standard and the Jacchia dynamic atmosphere models. RMDAP's Jacchia model requires the user to input the daily and 90-day average solar flux and the three-hourly and yearly average geomagnetic indices, thus permitting complete flexibility in the choice of Jacchia models. Monster provides internally the values for these parameters for

the nominal Jacchia model; however, program modifications during compilation can be used to provide the same capability as RMDAP.

Monster also provides a U.S.S.R. dynamic atmosphere model. RMDAP permits the user to input a nonstandard atmosphere model in tabular form; specifically, atmospheric density, pressure and temperature, and the speed of sound all as functions of altitude may be input to create a model.

RMDAP also permits user definition of the upper and lower limits of the atmosphere. No atmospheric drag will be applied outside the specified range. Monster automatically sets the atmosphere limits as defined by the atmosphere model selected.

2.3 Drag Coefficient

A periodic drag coefficient may be desirable in studying the effects of atmospheric drag on a vehicle in a space-fixed, i.e. an inertial, attitude. The coefficient of drag varies according to the vehicle shape in the direction of the velocity vector and according to the vehicle altitude in the orbit. Monster provides for only a constant vehicle drag coefficient; however, the user may simulate a periodic coefficient by redefining its value at various points in the vehicle's trajectory. However, this would be a very time consuming and inefficient technique for multirevolution lifetime studies.

RMDAP permits the drag coefficient to be input in any of several tabular forms. The value of the drag coefficient can be defined by a constant, a polynomial expansion, or a set of paired values. Step, linear, or quadratic interpolation may be selected to obtain the drag coefficient if a set of paired values are specified. Several extrapolation techniques are also available to the user. The argument or independent variable of the function can be chosen from a list of about 600 RMDAP input variables, which includes true anomaly, mach number, angle of attack, ground-elapsed time, and altitude. Tables can be constructed so that the coefficient of drag is a function of two parameters. A wide range of possibilities is provided for defining the drag coefficient in RMDAP; however, it should be noted that it is recomputed every time it is referenced, which represents added computer time.

2.4 Vehicle Mass

Both programs allow input of a constant vehicle mass, which satisfies the general case of constant mass for a vehicle coasting in orbit; however, a change in mass due to propellant boiloff or orbit keeping activities will affect orbital lifetimes. The decrease in mass due to orbit maintenance propellant costs is performed internally in RMDAP and Monster; propellant boiloff is not considered.

RMDAP's execution structure is broken into coasting and thrust phases. The user can divide each coasting trajectory into several subphases. A capability is provided in RMDAP that will automatically decrement the mass at the beginning of each phase by a fixed amount. The user can also decrement the mass by inputting a new value for the vehicle's mass for each phase. A technique similar to the latter may be employed in Monster, but not as efficiently.

2.5 Effective Drag Area

Both Monster and RMDAP require as input a constant effective drag area. This may suffice for an earth-fixed, local vertical local horizontal (LVLH) vehicle attitude producing a constant drag area, but it does not suffice for the inertial attitudes which generate a periodic projected area normal to the velocity vector. As with mass changes, the user can redefine the area at the beginning of phases or trajectory segments in RMDAP and Monster.

Another possible technique for implementing a variable effective drag area within RMDAP is to utilize the function definition available for the drag coefficient. The input drag area would be constant and any fluctuations in the drag area would be reflected by the value of the drag coefficient as defined by the function selected. The coefficient of drag could be made a function of true anomaly or right ascension for short lifetimes.

2.6 State Vector Initialization

RMDAP provides a selection of eleven state vector initialization coordinate systems with the earth or moon as the central body. Any of seven combinations of distance and velocity measurement units may be elected for inputting the coordinates. Monster has available seven coordinate systems for earth or lunar orbits; the selection of units is dependent upon the coordinate system chosen.

2.7 Orbit Keeping

Monster has a general purpose maneuver processor which performs most, if not all, of the maneuvers that may be required for orbit maintenance. Circularizations, height maneuvers, and apogee and perigee adjustments at a given altitude, longitude, latitude, or time are available. Specification of the maneuvers is straightforward; but one drawback for orbit keeping is that every maneuver as well as the threshold time for each maneuver must be input. This is inconvenient since the user must estimate the time of each maintenance maneuver, perhaps over a period of several days. For determining propellant costs for orbit maintenance, Monster does not keep a running sum of the velocity change (ΔV) required.

RMDAP's orbit keeping capabilities are not as well comprehended from available documents as Monster's. There does appear to be

available options to achieve specified circular and elliptical orbits and to perform Hohmann transfers without foreknowledge of the magnitude of the burn or ΔV required. An attempt to test the ease of performing orbit maintenance with RMDAP was not made for this study.

2.8 Trajectory Predictor Models

The trajectory predictor models provided with Monster are an integrator, the analytic ephemeris generator (AEG), and the Keplerian AEG. There is also an integrator and AEG combination available which automatically selects a model determined by orbit eccentricity (AEG for $e \leq 0.8$). The integrator-only mode does not consider atmospheric drag. All other effects are presumed to be considered by each model.

RMDAP utilizes the following trajectory determination models: Encke integration by fixed or variable step, Cowell integration by fixed or variable step, high-speed analytic two-body conic propagation, Analytic Orbit Prediction Program, and a multiconic propagation technique for earth-moon trajectories. Perturbations are included in each model; the effects of an oblate earth can be turned off for the Encke and Cowell models.

2.9 Event Termination

The processors in Monster terminate when a user specified time

has elapsed. This created problems with a recent orbital lifetime study using Monster's g.e.t. of apogee and perigee processor. After the orbit had decayed into a very low altitude nonconic orbit, a mathematical function routine error forced the computer's operating system to terminate execution of the remaining cases to be examined.

RMDAP has a special phase termination feature which allows the user to specify upon what condition or combination of conditions execution of a particular phase should terminate. Among the many termination options available are termination at a specified altitude, orbit count, radius vector, perigee radius, apogee radius, atmospheric density, drag force and time. Processor termination on altitude may have prevented premature execution termination by the operating system of the Monster program cited above, if Monster had had a similar event termination feature as RMDAP's.

3.0 COMPARISON TEST

A sample lifetime study was performed using both Monster and RMDAP to compare results. In the test, the shuttle orbiter was assumed to be in a low altitude orbit having an initial apogee altitude of 120 nautical miles (n.mi.) and an initial perigee altitude of 65 n.mi. The 190000 pound weight and 2.0 drag coefficient of the orbiter were assumed constant, and the same nominal Jacchia atmosphere model was employed. Three effective drag areas were

considered: 450, 2000 and 3930 square feet (ft^2). During each case, the effective drag area was assumed constant. No orbit maintenance was performed.

Orbital lifetimes were based upon an orbit altitude decay to 60 n.mi. Monster's groundtrack processor was employed to print out the orbiter's altitude every five minutes; the AEG trajectory prediction model was used. The lifetimes computed by Monster were approximately 1 day 16 hours 10 minutes (450 ft^2 area), 9^h20^m (2000 ft^2 area), and 4^h55^m (3930 ft^2 area). Altitude was measured above a spherical earth of radius 3443.933^r n.mi.

RMDAP was set up to output the geographic and geocentric osculating elements print blocks at every apogee and perigee crossing. Encke fixed step integration incorporating an oblate earth was used. For each area considered, the orbiter dropped below 60 n.mi. after approximately 37.2 minutes. This sudden decay was evidently due to the effects of the oblate earth. According to Reference 3, oblateness will produce a drop of about 9 n.mi., in the instance at first perigee, for an orbit set up similar to this test case.

RMDAP was rerun with the oblate earth flag turned off. This time the results were in practically complete agreement with Monster's predictions: $1^d16^h4^m$ (450 ft^2 area), 9^h23^m (2000 ft^2 area) and 4^h59^m (3930 ft^2 area). In Monster, a coordinate system combining apogee and perigee altitude with other geographic and classical

orbital elements was used to input the initial state vector. By analyzing the initial state vector output by Monster, it was found that the semimajor axis was 4.5 n.mi. longer than requested. It appears that Monster accounts for an oblate earth by creating a trajectory which produces first revolution results most nearly agreeing with the desired initial apogee and perigee altitudes.

The execution times for Monster and RMDAP were 12^m10^s and 7^m45^s, respectively. However, processors with different frequencies of output were implemented, and consequently the program execution times for this example do not provide a good gauge for comparing the running times of the two programs.

4.0 CONCLUSION

RMDAP and Monster provide similar features for orbital lifetime studies, but RMDAP has some extra capabilities that may permit a more comprehensive analysis. The tabular entry feature of RMDAP has great potential for modeling the effects of atmospheric drag as a function of orbital position and vehicle attitude. The maneuver processor of Monster seems to provide the greater flexibility for performing orbit maintenance. Based upon present knowledge, it is difficult to conclude that one program is clearly preferable to the other. It will probably be expedient for the orbital lifetime investigator to use the program more familiar to him.

5.0 REFERENCES

1. Reference Mission Design and Analysis Program User's Manual. TRW Document 20029-H148-RO-00, dated December 28, 1972, revised October 18, 1973.

2. Input/Output Manual for the Apollo Mission Planning and Real-Time Rendezvous Support Program, Volume I - Input. JSC Internal Note 74-FM-72, dated October 16, 1974.

3. McDonnell Douglas Corporation: General Explicit Formulation of the First-Order Effects of Planet Oblateness on Satellite Orbits. GCMN No. 109, dated March 6, 1963.

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